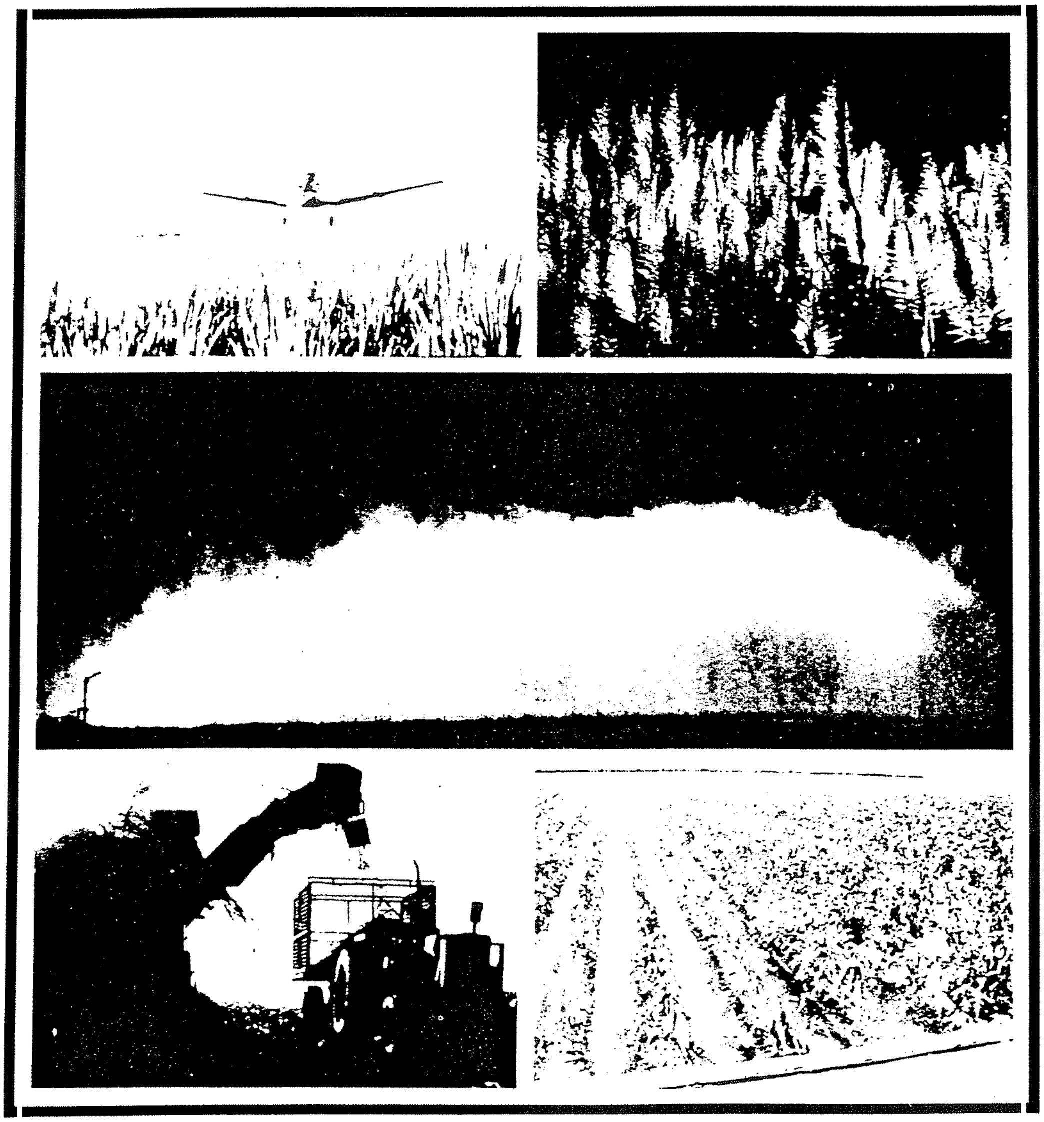
# Sugar Cane



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# Measuring terminal velocities of ash from cane burning

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*Summary*

**Vegetative ash released by prescribed fires conducted in the cane fields of south Florida frequently drifts into the surroundings. Regulation has decreased the number of urban incidents but conflicts remain and the sugar industry is often blamed for ash from other fires.**

**A numerical model to simulate the movement and deposition of cane ash assists regulators in locating offending fires and in permitting prescribed fires. The terminal velocities of vegetative ash are required inputs to this model.**

**Two separate ash samples, one taken in the laboratory and the other in the field, were analyzed as neither was considered representative. Differences existed between the two samples, but terminal velocities were similar in magnitude and distribution and thus could be combined.**

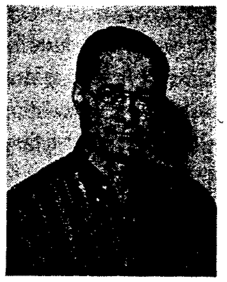
**It was concluded that the terminal velocities of "nuisance" sugar cane ash range from 0.2 - 0.8 m/sec and are largely independent of the size of the ash particles.**

*Introduction*

The Florida Sugar Industry annually harvests approximately 427,000 acres of cane in south Florida[1]. As a preharvest practice, cane fields are treated with prescribed fire for two reasons. First, fire eliminates waste biomass that would decrease the efficiency of the milling process. Second, fire controls snakes and other vermin that pose health hazards to harvesting crews.

However, prescribed fire in cane fields negatively impacts the larger environment when vegetative ash is transported and deposited over populated areas along the Florida east coast.

In 1971, the Florida Division of Forestry began to regulate the time of day the sugar industry could burn. Regulation became much more restrictive in 1991 after the implementation of permit criteria based on wind direction and



**Gary L. Achtemeier**

speed[2]. Since 1991, the number of complaints about ash deposition in residential areas near the Florida east coast has fallen from nearly 100 to just a few each year.

However, the question of whether agricultural burning is over-regulated, especially in the sugar cane growing areas located southwest of Lake Okeechobee, remains unanswered. This question exists partly because the dynamics of ash transport are poorly understood. In addition, the sugar industry is occasionally blamed for ash fallout from fires that originated elsewhere. Increased knowledge about the transport and deposition of airborne fire products may help answer this question and perhaps ease regulations, while maintaining relatively ash-free skies over south Florida.

***The modelling approach***

A comprehensive modelling system for sugar cane prescribed fire has been developed to provide industry and regulatory interests with accurate real-time prediction of ash deposition. Ash deposition is displayed for as many as 50 simultaneous fires on a GIS basemap of south Florida.

The model has the following applications to the ash deposition problem. First, it may be used for permitting prescribed fires. Second, when combined with the locations of complaints of ash deposition over urban areas, the model can diagnose offending fires. Third, time-dependent graphical display of evolving ash deposition patterns makes the model an excellent instructional tool.

The modelling philosophy treats ash as an ensemble of individual particles that are independent of neighbouring particles. The model is similar in many respects to Lagrangian plume dispersion models equipped with a Monte Carlo scheme for subgrid scale velocities[3]. In contrast with calculating concentration, translation, and dispersion via empirical formulae, the particle modeling approach better approximates the

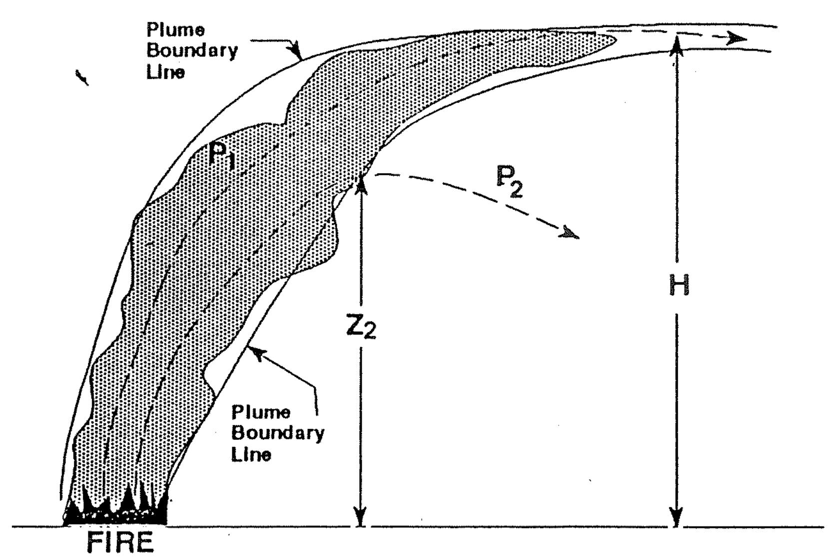



**Figure 1. Schematic showing trajectories of ash particles through a smoke plume**

dispersion of ash in a variable wind field characterized by strong vertical shear and divergent flows.

Once an ash particle leaves the immediate vicinity of the fire, the problem becomes one of understanding the meteorology of the ascending plume of smoke and ash and the meteorology of free fall through airmasses below the plume. Figure 1 illustrates this philosophy schematically. In trajectory $P_1$ an ash particle is carried from the fire to the top of the plume at some level H while in trajectory $P_2$ the ash particle falls out at some intermediate level. Where the ash returns to ground is determined by how long it remains within the plume, the elevation at which it departs from the plume, and its residence time free falling back to earth. These factors are all critically dependent on terminal velocity.

An example of sugar cane ash is shown in Figure 2. Cane fires burn hot and are therefore extremely turbulent. Combustion of dead plant material near the ground places green, leafy material near the top of the plant within the flaming zone. This material is torn apart and carried aloft once pyrolization has sufficiently weakened leaf structures. Thus, sugar cane ash consists of flat irregular strips of incompletely combusted leafy material. These strips present a large cross-section relative to mass to the atmosphere as they fall. Therefore, the relationship between size, aerodynamical drag, and terminal velocity of sugar cane ash is unclear.

**Figure 2. Video image analysis system used for measuring particle area and density. Camera and ash sample are in the foreground. Digitized display is shown on the monitor in the background**

### *Objective of the study*

The objective of this study is to provide the ash deposition models with a range of terminal velocities that is representative of the range of terminal velocities found in "nuisance" ash put into the atmosphere by cane fires. As the modelling system could contribute to permitting decisions for prescribed burning of sugar cane, it is critical that terminal velocities of vegetative ash are from sugar cane.

A search of the literature and discussions with research personnel involved with production of sugar cane in Florida uncovered no existing data on terminal velocities for sugar cane ash. The methodology for collecting ash samples and the techniques for obtaining the desired terminal velocities are described below.

### *Materials and methods*

A multi-agency field project to collect data on the transport and deposition of ash from sugar cane prescribed fires was conducted at sugar cane growing areas south of Lake Okeechobee from 1st - 11th November 1994. The project involved the Florida sugar industry, the USDA Forest Service, the Florida Division of Forestry, and the Florida Sugar Cane League. The 66 sq. mile (170 km$^2$) project area, located south of Lake Okeechobee, is highlighted in Figure 3. Each square represents a 1 mile section. The site was selected because the land was owned by a single corporation, thus making for easy accessibility, and detailed field maps were available containing highways, roads, and service lanes, thus making for easy mobility.

Conceptually, one could locate beneath an ash/smoke plume, capture ash as it falls, and drop it through a fall chamber to measure the terminal velocity. However, a representative distribution of terminal velocities cannot be gained in this way because those particles with smaller terminal velocities drift beyond the project area.

If U is the mean advecting wind speed through a layer of air of depth H containing the plume and if L is the distance from the fire to the edge of the project area, then the smallest terminal velocity an ash particle can have and fall within the project area is $w_s$ = UH/L. If, typically, U = 5.0 m/s, H = 1.0 km, and L = 10 km, then $w_s$ = 0.5 m/sec. Thus in-field capture of ash must be limited to the larger, heavier particles.

Several methods for collecting field ash were attempted. The most successful approach was to capture ash particles individually on a hand-held screen. This

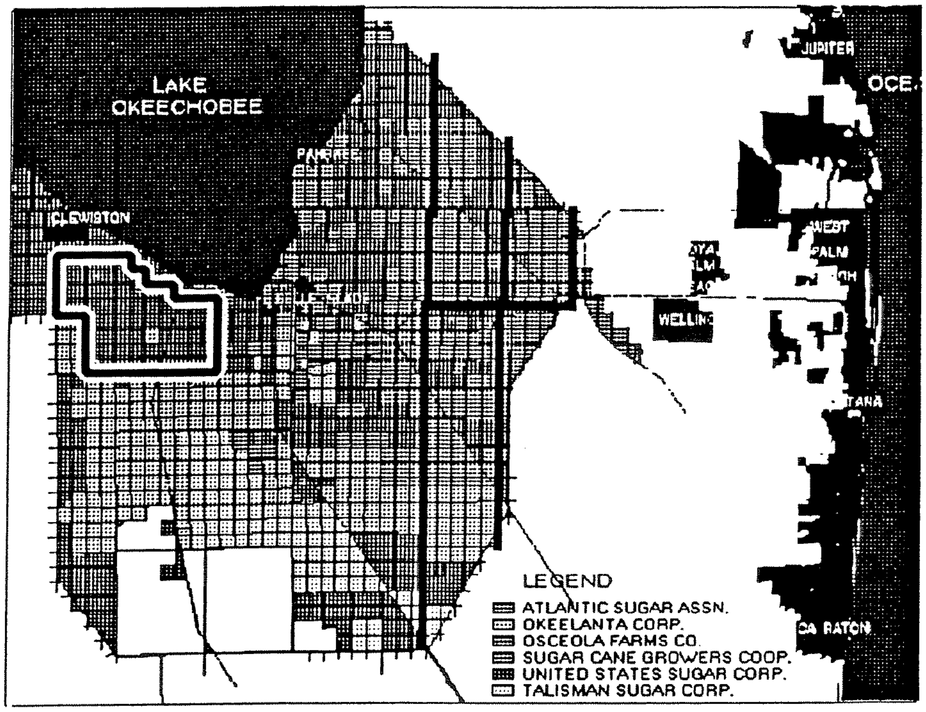



**Figure 3. Basemap showing sugar cane growing areas south of Lake Okeechobee, Florida. Urban areas along east coast are shown in black. Project area south of lake is highlighted. Map was obtained from screen grab of a colour GIS computer display**

practice further biased the data set toward larger particles that could be easily seen.

To supplement the field ash data set, parts of sugar cane plants were collected from the field, burned in the laboratory, and the ash carried aloft in the combustion columns was captured. This data set gave the most complete size distribution of ash. However, there remained the question of whether ash produced from sugar cane burned in the laboratory was representative of ash produced from sugar cane burned in the field.

Because the field ash data set was biased toward larger particles and the lab ash data set was obtained under different firing conditions, the experimental design called for analysis of the two data sets separately. Therefore particle area and density (darkness) were measured along with terminal velocity. These data were subjected to statistical analysis to test the hypothesis that the lab and field data sets were similar and could be combined into a single data set.

Once collected, field and lab ash were stored in covered cake pans for later analysis. Subsets of 258 particles from the lab data set and 206 particles from the field data set representing the full range of sizes of collected particles were selected for analysis and individually catalogued. Each ash particle was dropped through a $0.3 \times 0.3 \times 1.5$ m calibrated ash fall chamber. All falls were recorded with a video camera fitted with a character generator that provided an onscreen display of elapsed time. Resolution was 0.1 sec. The video tape was replayed on a video tape recorder and the output was fed into a video image analysis system. The video image analysis system was calibrated by placing a length and width reference in the field of view and in the fall plane of the particle. Free fall velocities were calculated by dividing the distance fallen by the elapsed time. Terminal velocities were assigned when free fall velocities maximized to a constant, which generally occurred above levels where particle fall was recorded.

Area and optical density (darkness) of the ash particles were measured with a video image analysis system (Figure 2). The particles were backlit on a transilluminator and measures of optical density and cross-sectional area were taken from these silhouetted images. Optical density (OD) is determined by measuring the intensity of light incident ($I_i$) or shining on a specimen and the intensity of light detected ($I_d$) after passing through the specimen[4]. Optical density was calculated from,

$$OD = \log ( I_i / I_d ) \qquad (1)$$

Then cross-sectional area and average particle density in units of log inverse gray scale were filed for statistical analysis.

Regression models were fitted to the lab and field data separately. If models of the same functional form could be fitted to both lab and field data and corresponding model parameter estimates were homogeneous, then the two samples could be combined, resulting in a data set containing the better size distribution of the lab sample and the ground truth of the field sample.

## *Results and discussion*

### *Comparison of lab and field ash*

Figure 4 shows distributions by cross-sectional area of the ash particles selected for analysis. 80% of the lab ash particles were less than 25 mm$^2$ and more than 50% were less than 10 mm$^2$. By contrast, a larger percentage of field ash particles were between 25 mm$^2$ and 100 mm$^2$. These differences were expected because the field data set was biased toward larger particles.

Figure 5 shows relative distributions by density of lab ash and field ash. Most lab ash densities fell between 0.3 and 1.0 with a peak near 0.5. Most field ash densities fell between 0.6 and 1.3 with a peak near 1.0. Thus the field ash was mostly darker than the lab ash.

Because field ash was also generally larger than lab ash, differences in darkness may be assumed to be just a

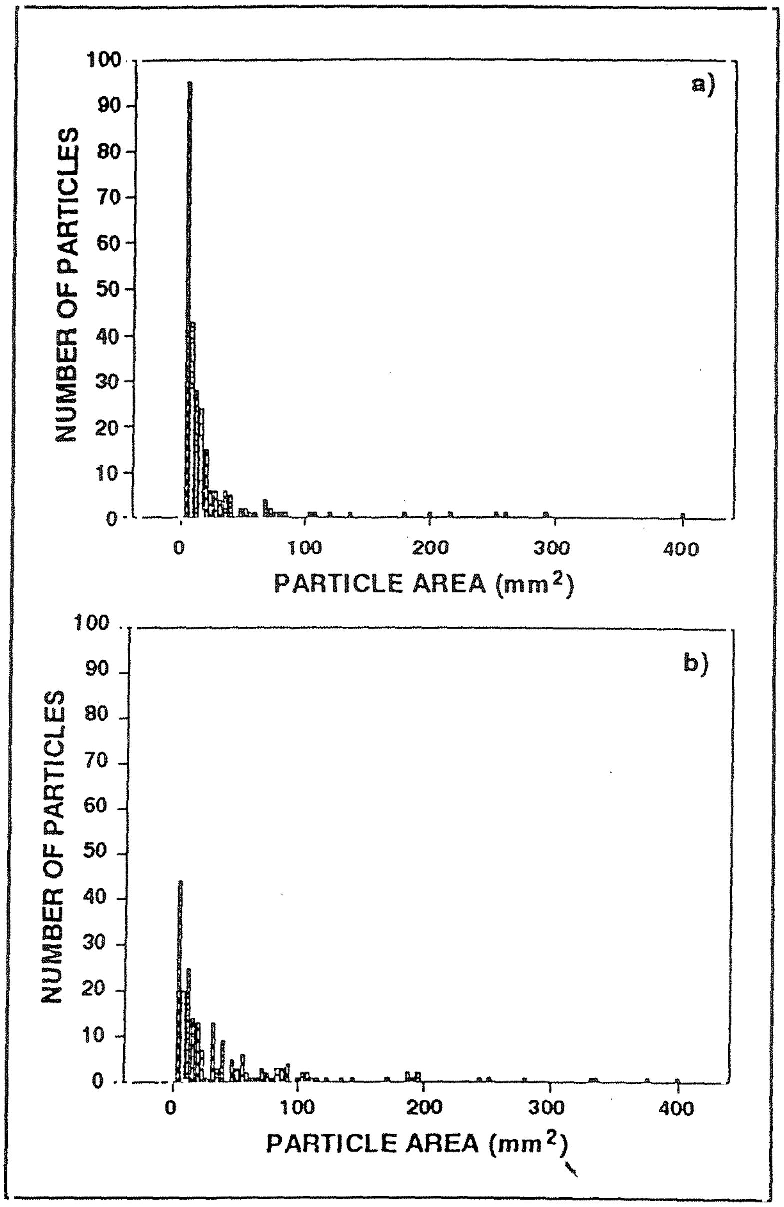



**Figure 4. Sugar cane ash number density as a function of cross- sectional area for (a) 258 lab particles and (b) 206 field particles**

function of size. Figure 6 compares particle size with density for the two samples. There is no relationship between size and density for particles 25 mm$^2$ or less in area for either lab or field ash. A positive relationship exists for particles larger than 25 mm$^2$ – small particles are generally light and large particles are generally dark.

More significant for the purposes of this study are comparative densities between lab and field ash. Field ash particles are darker than lab ash for all size categories larger than 25 mm$^2$. For example, more field ash particles (Figure 6b) than lab ash particles (Figure 6a) of all sizes are darker than density 1.2 (dashed line).

Thus, the differences in darkness do not exist because field ash is larger than lab ash. The differences are more likely to exist because the hot and turbulent cane fires tore apart and lofted vegetative material before combustion was complete.

The most significant finding from the analysis of ash terminal velocities is that there appears to be an upper limit on terminal velocities for large particles. Figure 7 shows terminal velocity as a function of particle cross-sectional area. The horizontal dashed lines delineate the terminal velocity range 0.4 - 0.7 m/s. Most particles of lab ash greater than 50 mm$^2$ are found within this terminal velocity range (Figure 7a). Most particles of field ash greater than 100 mm$^2$ fall within the same range (Figure 7b). Therefore, for larger particles, terminal velocities for lab ash and field ash are essentially the same.

General similarities also exist between lab and field ash for smaller particles. The speed range is mostly 0.2 - 0.8 m/s for lab ash from 10 - 100 mm$^2$ (area between the two vertical lines). Most field ash terminal velocities fall within the same range but there is a greater concentration of particles in the 0.2 - 0.5 m/s range. Speeds range from 0.1-1.0 m/s for particles in both data sets less than 10 mm$^2$. Many of the small particles present relatively small cross sections to the atmosphere and thus approach the aerodynamics of fly ash[5].

These results show that terminal velocities of lab ash and field ash may be combined with confidence and that the limits of terminal velocities for sugar cane fires in the field fall within the limits of 0.1 - 1.0 m/s found from these two samples.

*Eliminating small particles*

The range of terminal velocities can be narrowed. As mentioned earlier, wind conditions and the size of the project area limited field ash capture to the larger particles and the use of hand-held screens further biased field ash capture to those large particles that could be easily seen. The very small particles less than 10 mm$^2$ were not captured as they fell but were more likely to be fragments of larger particles that broke apart upon impact with the screen. Therefore they do not represent field ash for the small size category.

Replacing field ash terminal

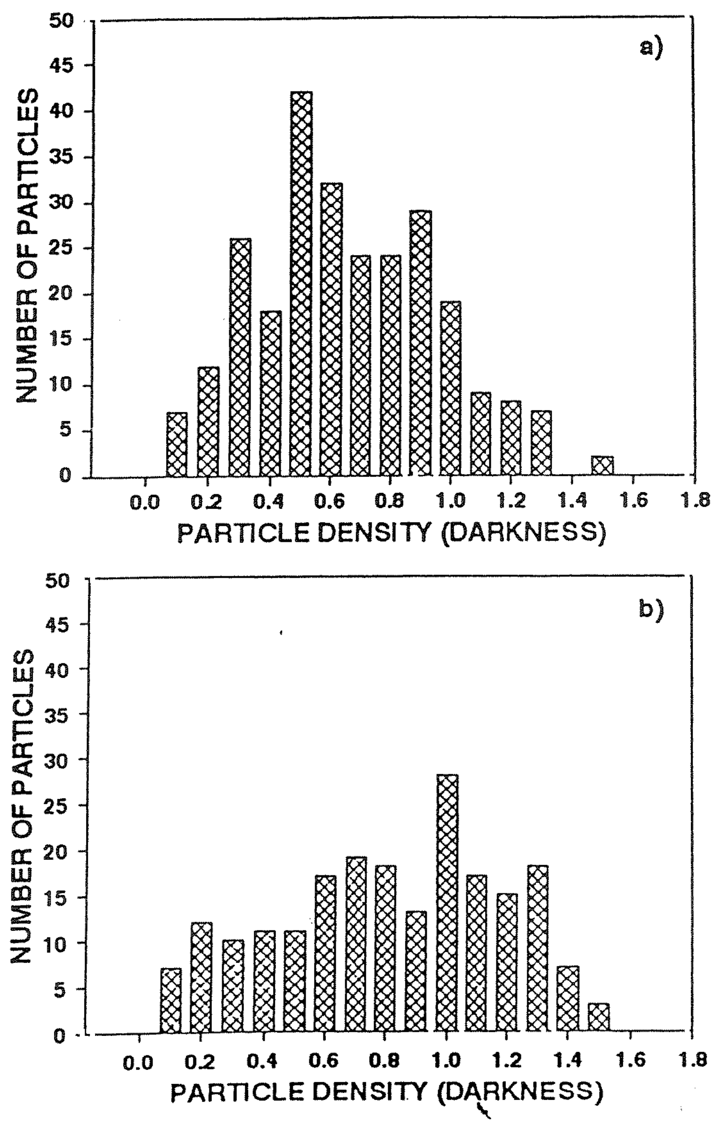



**Figure 5. Number of particles in density (darkness) categories from white to near black for (a) lab ash and (b) field ash**

velocities with lab ash terminal velocities for particles less than 10 $mm^2$ eliminates the speed "spike" for small particles in Figure 7b. The upper limit on terminal velocities is reduced to about 0.8 m/s.

In addition, most particles with terminal velocities less than 0.2 m/s measure less than 10 $mm^2$ and are not noticed unless they fall in great concentration. These tiny particles should disperse over great distances and not present a nuisance. Therefore, these particles are unimportant to the numerical calculations. Eliminating them reduces the range of terminal velocities for the ash fall and deposition model to 0.2-0.8 m/s.

Part of this study was devoted to comparing measurements of area, density, and terminal velocity between the two data sets to determine whether they could be combined statistically. Correlations between any of cross-sectional area, density, and terminal velocity for either lab or field ash were non-existent or small. Therefore, the hypothesis that both data sets could be combined could be neither proven nor disproven.

*Limitations of the study*

The 1994 field project did not include measurements of the total mass of vegetative material released to the atmosphere during a typical sugar cane burn, nor observations of particle size distribution and number density. Although the combined data sets presented in this study are probably representative of size distribution, the absence of data on number density and total mass released makes quantitative estimates of deposition impossible. We instead use "relative" deposition from a "unit fire" and capitalize on the lack of correlation between cross-sectional area and terminal velocity, with the caveat that all particle sizes and terminal velocities are equally probable.

*Acknowledgements*

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## Medición de la velocidad terminal de la ceniza proveniente de quema de caña

La liberación de ceniza vegetal ocasionada por la quema de la caña conduce a que en los campos de caña del sur de la Florida ésta se amontone frecuentemente en los alrededores. La regulación ha disminuido el número de incidentes urbanos pero los conflictos permanecen y la industria azucarera es a menudo culpada por la ceniza de otros tipos de fuegos.

Un modelo matemático que simula

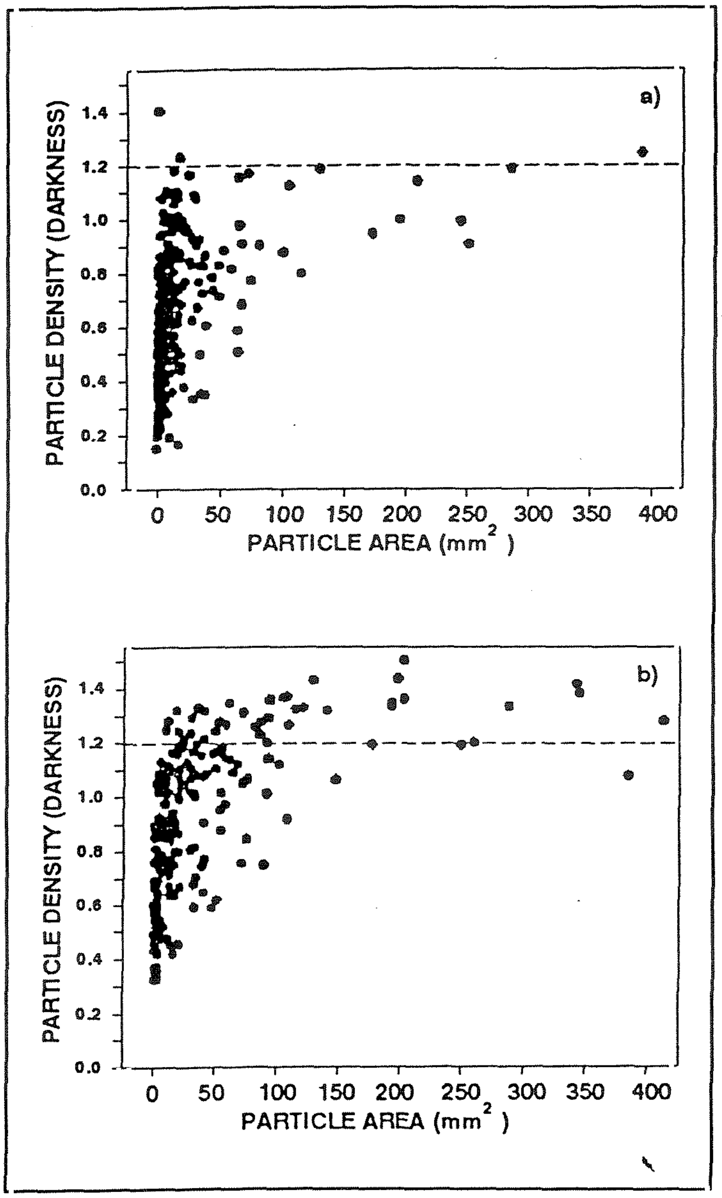


**Figure 6. Particle density (darkness) as a function of cross-sectional area for (a) lab ash and (b) field ash**

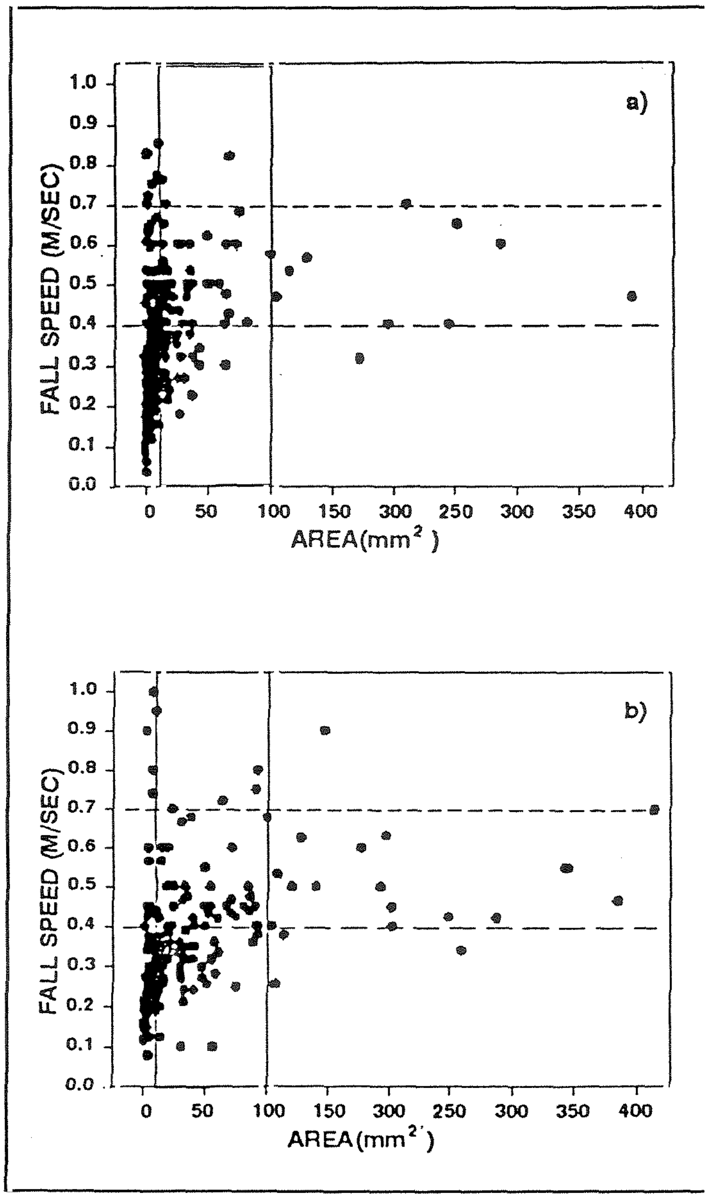


**Figure 7. Ash terminal velocity as a function of cross-sectional area for (a) lab ash and (b) field ash**

el movimiento y la deposición de la ceniza de caña ayuda a los reguladores a localizar los fuegos ofensivos y permite determinar el fuego. La velocidad terminal de la ceniza vegetal es requerida como dato de entrada al modelo.

Dos muestras distintas de ceniza, una tomada en el laboratorio y otra en el campo, fueron analizadas pues ninguna de las dos fue considerada representativa. Existieron diferencias entre las dos muestras, pero las velocidades terminales fueron parecidas en magnitud y distribución y de este modo pudieron ser combinadas.

Esto concluyó en que la velocidad terminal de la ceniza de caña de azúcar está entre el rango de 0.2 a 0.8 m/seg y es muy independiente del tamaño de la partícula.


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